



# Conclusion to the special issue: Observed and projected changes in weather and climate extremes



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## ABSTRACT

Weather and climate extremes affect every facet of society-economies, environments and cultures. As a result, policy makers, planners, decision makers and other stakeholders are increasingly seeking information on the nature of such extreme events on time scales from hours to days, to seasons and to decades.

This Special Issue has presented a combination of original research and assessments of earlier work in relation to weather and climate extremes. The papers covered two major themes: (i) detecting and attributing changes in temperature and precipitation extremes in the observational record, as well as projecting changes in such extremes at regional and local scales; and (ii) examples of the impacts and other consequences of both the historic and anticipated changes in extreme weather and climate events, as well as policy implications and practical applications.

The papers in this Special Issue have shown the nature of the scientific and related challenges, the progress made to date, and the challenges, opportunities and constraints yet to be addressed. They have contributed to increased understanding of where, how and why such events manifest themselves, now and into the future. Such insights increase the capacity to manage the risks associated with these events, and thereby reduce the consequences that society might otherwise have suffered.

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## 1. Scope and focus

This Special Issue has presented a combination of original research and assessments of earlier work in relation to weather and climate extremes. The papers covered two major themes: (i) detecting and attributing changes in temperature and precipitation extremes in the observational record, as well as projecting changes in such extremes at regional and local scales; and (ii) examples of the impacts and other consequences of both the historic and anticipated changes in extreme weather and climate events, as well as policy implications and practical applications.

## 2. Progress

The Special Issue summarises and provides specific examples of the considerable progress made for both these topics in recent years, including in the few years since the IPCC's Fifth Assessment

Report (IPCC, 2013). Broadly speaking, warm temperature extremes have continued to increase and cold temperature extremes have continued to decrease, despite the warming hiatus in global mean surface temperature. Precipitation extremes also appear to have increased in more regions than they have decreased. This appears also to be the case for shorter-duration, intense rainfall for which there were limited data and studies from which to draw firm conclusions in the IPCC's Fifth Assessment.

High performance computing has recently enabled a new class of climate models that can better simulate extreme weather events in multi-decadal integrations. Although still a rapidly developing field, global high-resolution atmospheric general circulation models at resolutions of about 20 km are able to reproduce climate fields as well as regional-scale phenomena such as monsoonal rainfall, tropical and extratropical cyclones and heavy precipitation.

This increased resolution of new generation models reveals substantial spatial variability within relatively small sub-regions of the United States for both projected warm and cold temperature extremes, even within regions that often are considered relatively homogeneous. Globally, heavy precipitation indices (maximum

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5-day precipitation total and maximum 1-day precipitation total) are projected to increase in all regional domains, even where decreases in mean precipitation are indicated, such as in Southern Africa, South Europe/Mediterranean, and Central America. South Asia is the domain of the largest projected increases in extreme precipitation.

Satellite observations now have sufficiently long enough periods of record to be useful in classical style detection/attribution studies, and have also proven useful in event attribution. Further innovative uses of these data must be pursued. However, satellite and other remotely sensed data require considerable post-processing to correct for biases owing to problems such as orbital drift and changes in instrumentation.

Advances in extreme value statistical techniques are enabling more robust estimates of long period return values. Such reductions in the uncertainty of the statistical fits will allow improved detection and attribution of changes in extreme temperature and precipitation. This includes attribution of individual slow- or rapid-onset events. The findings are proving extremely effective when communicating well-founded climate change messages to the public at large.

### 3. Challenges, opportunities and constraints

Despite these impressive advances, Special Issue authors also highlight the challenges and constraints related to confident and practical application of the new capabilities. There is growing interest in the causes of extreme events, particularly if these can be linked to human-induced climate change. The science of attribution, particularly event attribution, is still emerging. If this information is to be useful to a wide range of stakeholders, uncertainties in attribution results need to be assessed and articulated in ways that stakeholders can understand.

There is a similar requirement if managing the impacts of extreme weather and climate events is to become more effective and efficient. Within the next decade research on changes in regional extremes is likely to produce “actionable” results that will inform risk reduction interventions. But again this will require careful consideration of uncertainty, and presentation of results in terms that are readily understood by stakeholders. Documenting and understanding the differences in projections developed using a variety of global climate models, downscaling tools and definitions for extremes will reduce the range and uncertainty of estimated changes by identifying unrealistic or inappropriate methods. Key to this process is identification and elaboration of physical mechanisms that drive changes in extremes, including their seasonal variations.

Authors note ongoing challenges with data availability and quality, the ability to monitor and report extreme events consistently and the capacity to develop and apply the complex statistical methods to undertake rigorous analyses.

While the amount of data available for analysis has increased significantly, there is still a lack of data in regions such as Africa and South America. In many parts of the world limited availability of high resolution observational data still presents a major constraint on the analysis of extreme weather and climate events. Globally there is a need to ensure free and unrestricted access to daily and sub-daily data. Another significant issue is the general mismatch in the spatial scales between observations that are usually made at point locations and model simulations. The latter are typically interpreted as representing an area of a model grid. The disparity is especially a problem for precipitation extremes, reducing confidence in interpreting and understanding the observed changes in the frequency, intensity and duration of such events. Various techniques are being used to grid or interpolate

station data to aid observation and model comparison, but additional work is required to identify and apply the most appropriate methods for each region.

The computing power required to undertake analyses of historic and projected extreme events at a global scale is now reaching a critical level, making it increasingly difficult for individual researchers to undertake the research. For example, Kitoh and Endo found the computer power required to undertake ensemble experiments for future projections using a 20 km resolution global climate model limited their study to only four experiments. This is insufficient to cover uncertainty ranges and obtain probabilistic regional climate information. As many as 100 experiments may be required. As an alternative, they used a 60 km version of the same model for ensemble experiments with many members, even though at this scale there are limitations on the ability to quantitatively reproduce tropical cyclone intensity. Solutions to such constraints may well require the computer science community to find innovative ways to optimise the use of computer resources.

### 4. Impacts and consequences

As noted above, improvements in projecting changes in weather and climate extremes at regional and local scales are flowing through to deliver advances in assessing the impacts and other consequences of such events, as well as policy implications and practical applications. Impacts of weather and climate extremes often result from simultaneous extremes in several variables. For that reason an emerging theme in the analysis of extreme events is bivariate or multivariate extremes. For example, understanding the influence of climate extremes on agricultural yield requires consideration of both growing season temperature and precipitation extremes. For human health considerations, prolonged periods with extreme temperatures and humidity are an important consideration. Often, application-dependent criteria are needed to translate changes in climate extremes to changes in impacts, taking into consideration underlying vulnerability. Hence detecting or projecting changes in extremes is only the first step toward reducing their adverse consequences.

Allowing for climate change when assessing the impacts of coastal hazards often requires accurate descriptions of tropical cyclones, including their genesis and tracks, as well as their frequency and intensity. The greatest climate- and weather-related impacts of sea level are due to extremes on time scales of days and hours, associated with tropical cyclones and mid-latitude storms. Low atmospheric pressure and high winds produce large local sea level excursions called storm surges, which are especially serious when they coincide with high tide. Changes in the frequency of occurrence of these extreme sea levels are affected both by changes in mean sea level and in the meteorological phenomena causing the extremes (IPCC, 2007).

Accurate characterisation of such events can be achieved using dynamical downscaling from regional meteorological models for specific events, or by way of statistical models. Both techniques are important for projections of storm surge height on a regional scale, including extreme storm surge and wave climate in middle latitudes. The latter approach increases the number of cyclones being analysed, while assessing the impacts of such extreme tropical cyclones on coastal environment emphasises the importance of considering worst-case cyclones on a scenario basis. Further studies are required in order to reduce uncertainties in projections of extreme coastal hazards.

Regional and local climate extremes, and their impacts, result from the multifaceted interplay between large-scale climate forcing, local environmental factors and societal vulnerability. As an

example, the health risks of climate change result from the interactions of the hazards arising from a changing climate (e.g. increases in the frequency and intensity of extreme weather and climate events), the exposure of individuals, families and communities to those hazards and their susceptibility to adverse impacts when exposed, and the capacity to prepare for and cope with the consequences of the hazards. Extreme events can simultaneously be current hazards and also directly and indirectly influence future vulnerability by, for example, affecting longer-term access to health care or an individual's mental health.

Improved understanding of sources of vulnerability before, during, and after an extreme event provides insights for improving management of the health risks of climate variability and change. A more nuanced understanding is needed of the pattern of risk and how it changes over time, the reasons for these changes, how these risks affect human health, and the longer-term consequences of extreme events for vulnerability. This knowledge is becoming increasingly important as the frequency and intensity of extreme weather and climate events increases with climate change.

Evaluation of climate model simulations in the context of multi-scale processes should also be a key focus for the next decade of research. Some progress has already been made. For example, coastal water levels that occur during a storm are influenced by atmospheric and ocean processes which operate on a range of timescales. In the South Pacific, storm surges and the associated coastal inundation are most commonly associated with tropical cyclones. High-resolution 1-D models are now capable of representing the instantaneous movement of waves across the reef, as well as wave run-up and overtopping at a seawall. These provide estimates of the instantaneous maximum sea levels and currents that may occur under different time-averaged wave and sea level conditions, as simulated by a lower resolution model for different tropical cyclone conditions. Such calculations are facilitated by the availability of high-resolution light detection and ranging (LiDAR) data for the reef edge, lagoon and adjacent land areas.

## 5. Policy and practical implications

Historical case studies of extreme events, such as for the 1950s U.S. drought considered in this Special Issue, provide opportunities to examine the ways in which social, technical and physical capital are mobilized through policies, planning and decision making. They also highlight that such mobilizations of capital are shaped by longer-term events and perceptions, and their conditioning factors. This emphasises the need to think far beyond the idea of event-based adjustment and once again acknowledge that weather and climate extremes, and their impacts, result from the multifaceted interplay between large-scale climate forcing, local environmental factors and societal vulnerability.

Thus responses to extreme events are conditioned by context, and are not well predictable from the scale or qualities of the weather or climate event alone, at least within historic ranges of variation. This demonstrates the need to avoid limiting analysis of climate-society interactions to the weather and climate events alone, or to inadequate sets of social interactions and areas.

Extreme weather events affect the core business of the insurance industry. As a result, very early on this sector began considering the ways in which natural catastrophe hazards are influenced by climate variability and by global warming. A global database of loss events caused by natural hazards over the last 40 years includes more than 36,000 events. Analyses of the data clearly show high interannual variability, with decadal oscillations in some regions. They also show a long-term trend of an increase in the number of natural catastrophes around the globe, by a factor of about three within the last 35 years, with ever growing losses.

The increasing number of natural catastrophes are predominantly attributable to weather-related events such as storms and floods, with no related increase in geophysical events such as earthquakes, tsunamis, and volcanic eruptions. As a result, there is some justification in assuming that changes in the atmosphere, and global warming in particular, play a relevant role. However, the main contribution to the upward trend of the losses caused by natural catastrophes comes from socio-economic/demographic factors such as population growth, ongoing urbanization and increasing values being exposed, underscoring the need to understand and project how climate and development could evolve over the present century.

Insurers need to invest more resources into analyses of trends in order to ensure that premiums for the risks they cover always reflect a dynamic hazard pattern. There is also a need to ensure that prevention measures, such as flood protection programmes, have a high potential to reduce losses even when hazard levels are increasing.

## 6. Concluding comments

Weather and climate extremes affect every facet of society-economies, environments and cultures. As a result, policy makers, planners, decision makers and other stakeholders are increasingly seeking information on the nature of such extreme events on time scales from hours to days, to seasons and to decades.

This Special Issue has shown the nature of the resulting scientific and related challenges, the progress made to date, and the challenges, opportunities and constraints yet to be addressed. Individually and collectively, the authors of this Special Issue hope that they have contributed to increased understanding of where, how and why such events manifest themselves, now and into the future. Such insights increase the capacity to manage the risks associated with these events, and thereby reduce the consequences that society might otherwise have suffered.

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